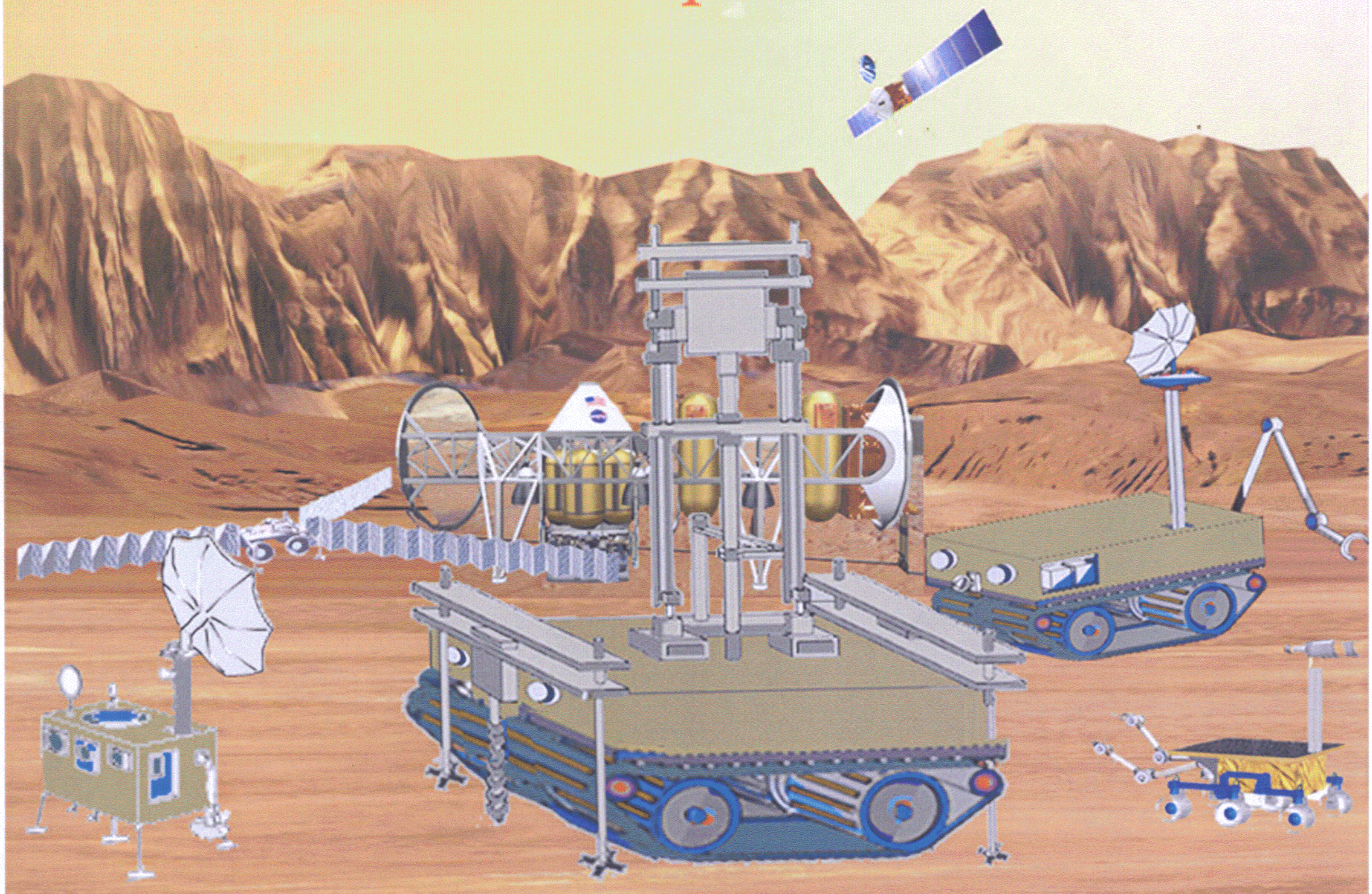
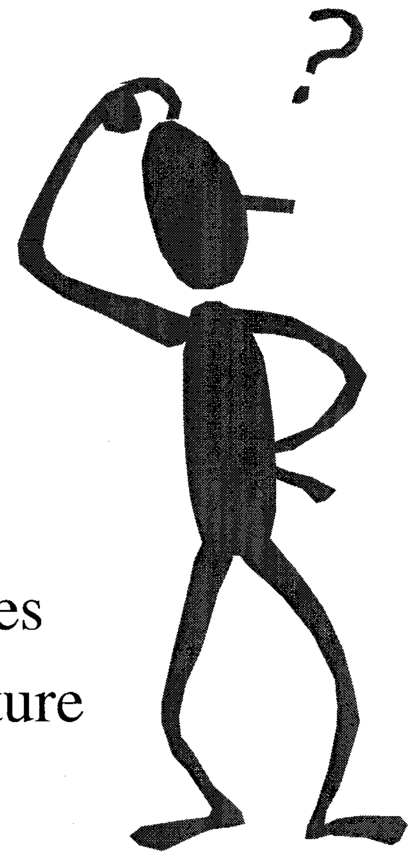
Future Mars Outpost Architecture



Tracy Williams, Jet Propulsion Laboratory
California Institute of Technology

Definition and Rationale

- What is an Outpost?
  - Series of Linked Missions
  - Logistical Support
  - Continuous, Long-Term Presence
- Why Create Outposts?
  - Collection of Long-Term Data Sets
  - Flexibility to Respond to New Discoveries
  - Emplacement/Maintenance of Infrastructure
  - Preparation for Human Exploration
  - Public Engagement



Formulation and Design

Design Process

- Multi-Mission Trades
- Technology Projection

Siting

- Long-Term Commitment
- Scientific/Operational Factors

Evolution

- Overall Strategy
- Flexibility

Logistics

- Single vs. Multi-Mission
- Long-Term Support

Outpost Study: Assumptions and Drivers

- Focus: Subsurface Characterization
- Operational Assumptions
  - Long-Lived Equipment
  - Autonomy
  - Mature Precision EDL
- Element Assumptions
  - Nuclear Reactor
  - Launch Vehicles
  - Continuous HDTV

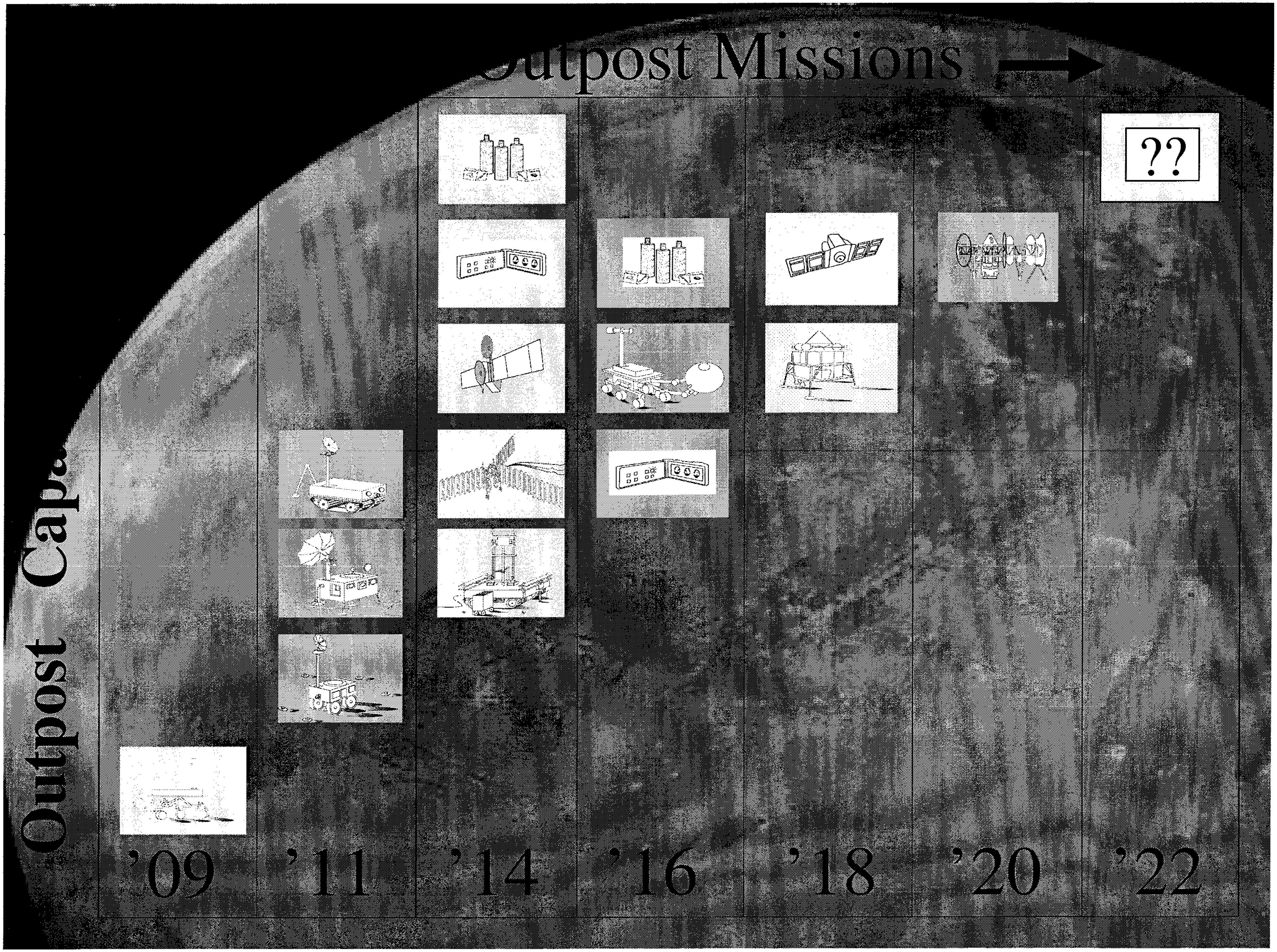
Elements by Opportunity

Launch Opportunity

Baseline Scenario		
Launch Opportunity	**Primary Payload(s)**	**Operational Objective(s)**
2009	Long Range Rover	Locate initial outpost site
	Navigation Beacon	Provide location signal for future landings
	HDTV Camera	Establish virtual presence
2011	Mars Towing Rover	Transport seismic lab and the drill, replace batteries for all rovers (using a robotic arm)
	Mobile Seismic Lab	Begin high-resolution subsurface mapping
	Communication Hub	Expand communication capability, support climate sensors to obtain continuous, long-term data sets
2014	Space Nuclear Reactor	Power the drill and other equipment
	Deep Drill	Calibrate seismic data and produce core samples
	In-situ sample analysis equipment	Analyze core samples from drill
	Logistics Supplies	Provide additional drill stems and tether
	Comm. Satellite	Expand communication capability
2016	Science Rover	Enhance mobile science capability
	In-Situ Science Instruments	Enhance science capability
	Logistics Supplies	Provide additional drill stems and tether
2018	Sample Return Orbiter	Provide Earth Return Vehicle for samples
	Mars Ascent Vehicle	Transfer samples from the surface to the orbiter
2020	Human Precursor Demos	Prepare for human exploration
	ISRU Equipment	Demo In-Situ Resource Utilization
2022	Advanced Robotic or Human Operations Gear	Enhance robotic capability and/or prepare for human arrival
	Advanced Mobile Units	Expand current outpost and/or traverse to new site

H_2O Contingency Scenario		
Launch Order	**Primary Payload(s)**	**Mission Objectives**
1	Wet Chemical Analysis Instruments	Add capability for analysis of liquid samples
2	Wet Sample Return Orbiter and Ascent Vehicle	Add capability for return of liquid and/or frozen samples
3	ISRU Systems	Add capability for utilizing H_2O resource

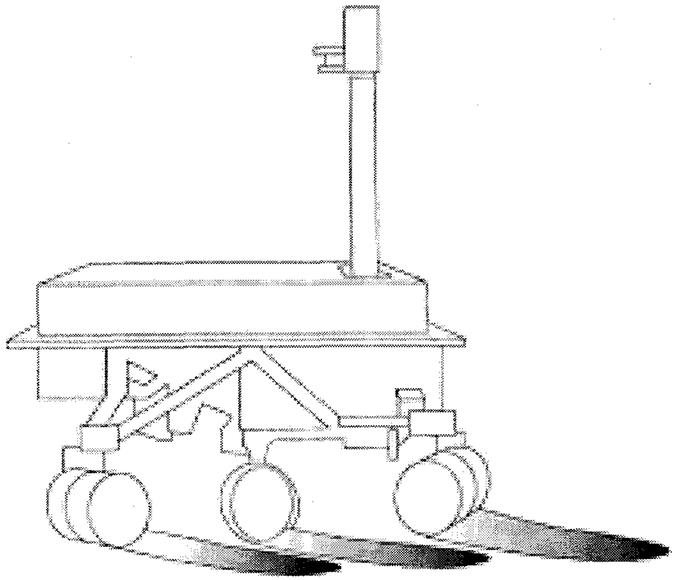
Mission Objectives



Outpost Missions
Outpost Capa
??
'09
'11
'14
'16
'18
'20
'22

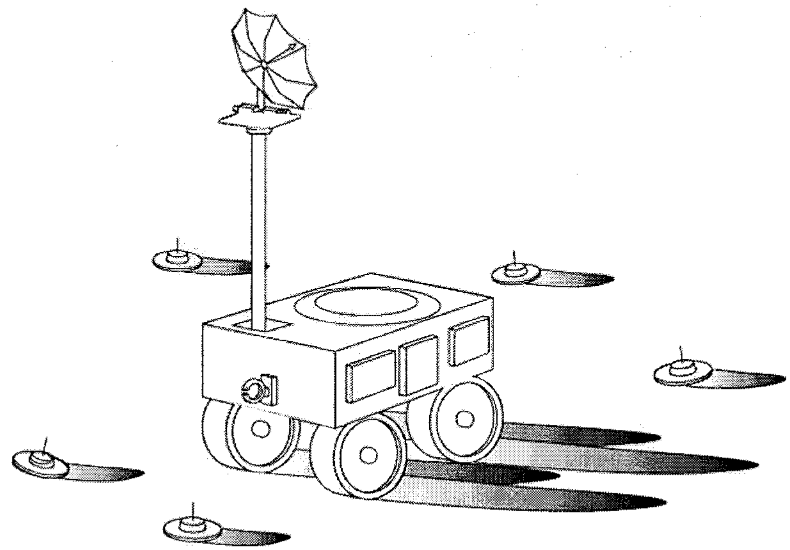
Mission I: Reconnaissance

- Objective: Pinpoint outpost site
- Elements
  - Long-Range Rover
  - Nav Beacon, HDTV Camera
- Rover Characteristics
  - Based on previous rover concept
  - Speed Range: 1-2 km per sol
  - Mass Range: 200-400 kg
  - Primary/rechargeable batteries
  - Launch Vehicle: Delta II class



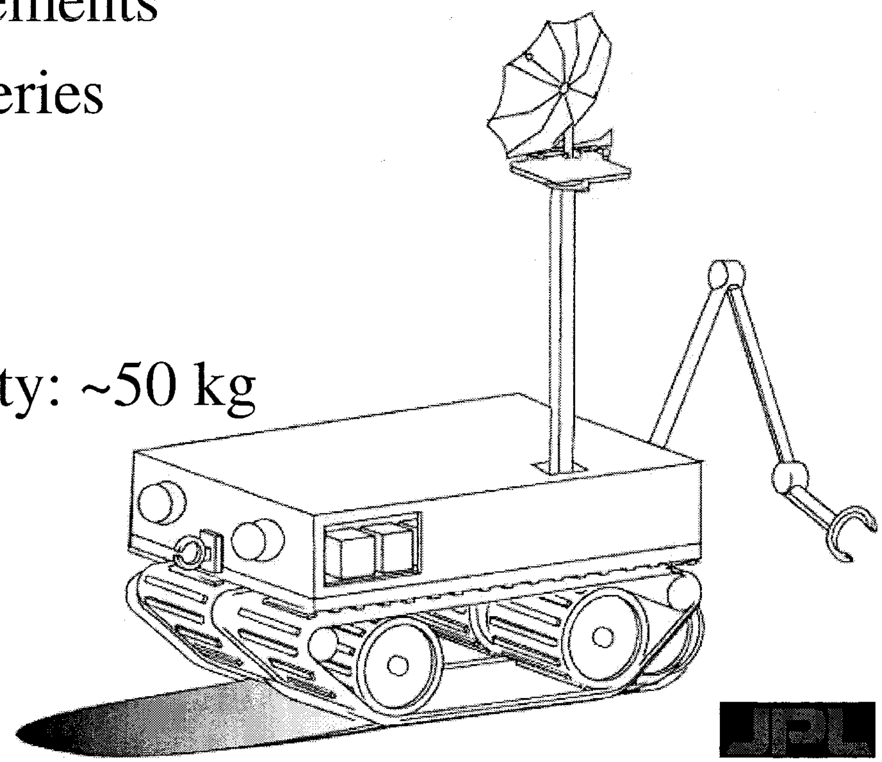
Mission II: Seismic Survey

- Objectives
  - Begin Subsurface Characterization
  - Select Drilling Site
  - Enhance Communications
- MSL Characteristics
  - Active sounding
  - 25 UBB seismometers
  - 100 charges
  - L-shaped array deployment
- Elements
  - Mobile Seismic Lab
  - Mars Towing Rover
  - Communications Hub



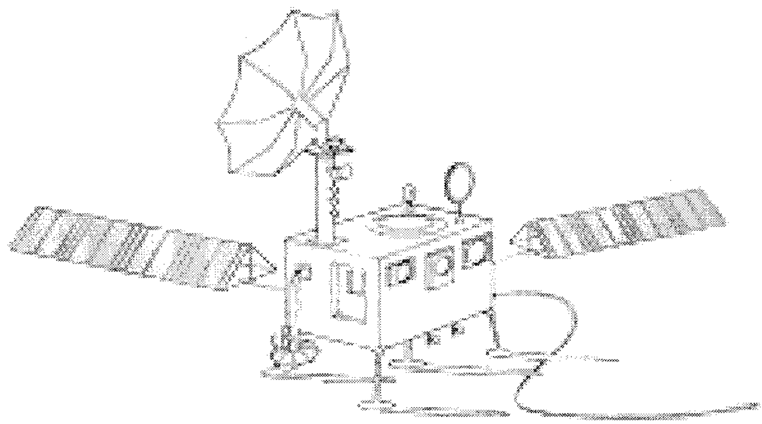
Mission II: Seismic Survey (2)

- Mars Towing Rover Tasks
  - Deployment of Seismic Lab, Power Tether
  - Transportation of Deep Drill, Communications Hub, Supplies and other Elements
  - Replacement of Rover Batteries
- MTR Characteristics
  - Mass Range: 800-1000 kg
  - Robotic arm lifting capability: ~50 kg
  - 1500+ kg towing capability
  - Rechargeable Batteries
  - Includes HDTV camera



Mission II: Seismic Survey (3)

- Communications Hub
  - Design Driven by 20 Mbps HDTV Data Stream
  - 5-m High Gain Antenna
  - X- or Ka-band for communication with DNS
  - Initially Battery/Solar Powered
  - Ultimately Tethered to Reactor

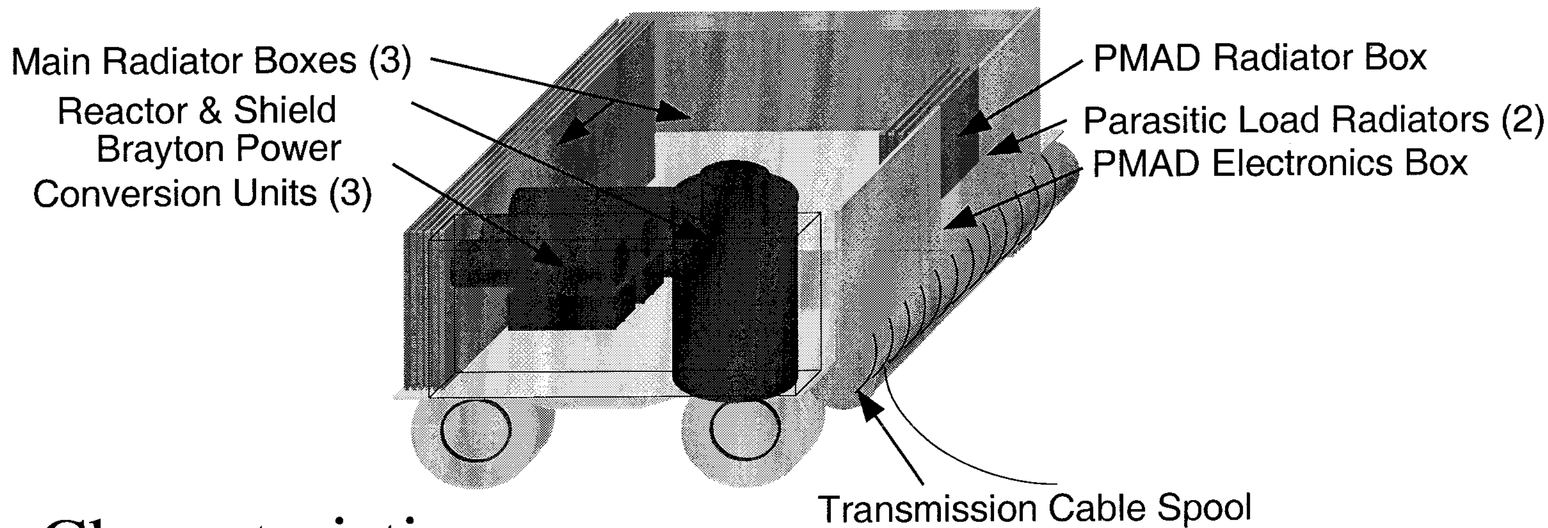


Mission III: Drilling Campaign

- Objectives
  - Intensify Subsurface Characterization
    - Acquire core samples for analysis
    - Provide ground truthing for seismic survey
  - Expand Communications Capability
- Elements
  - Deep Drill
  - Nuclear Reactor
  - Communication Satellite
  - Logistical Supplies

Mission III: Drilling Campaign (2)

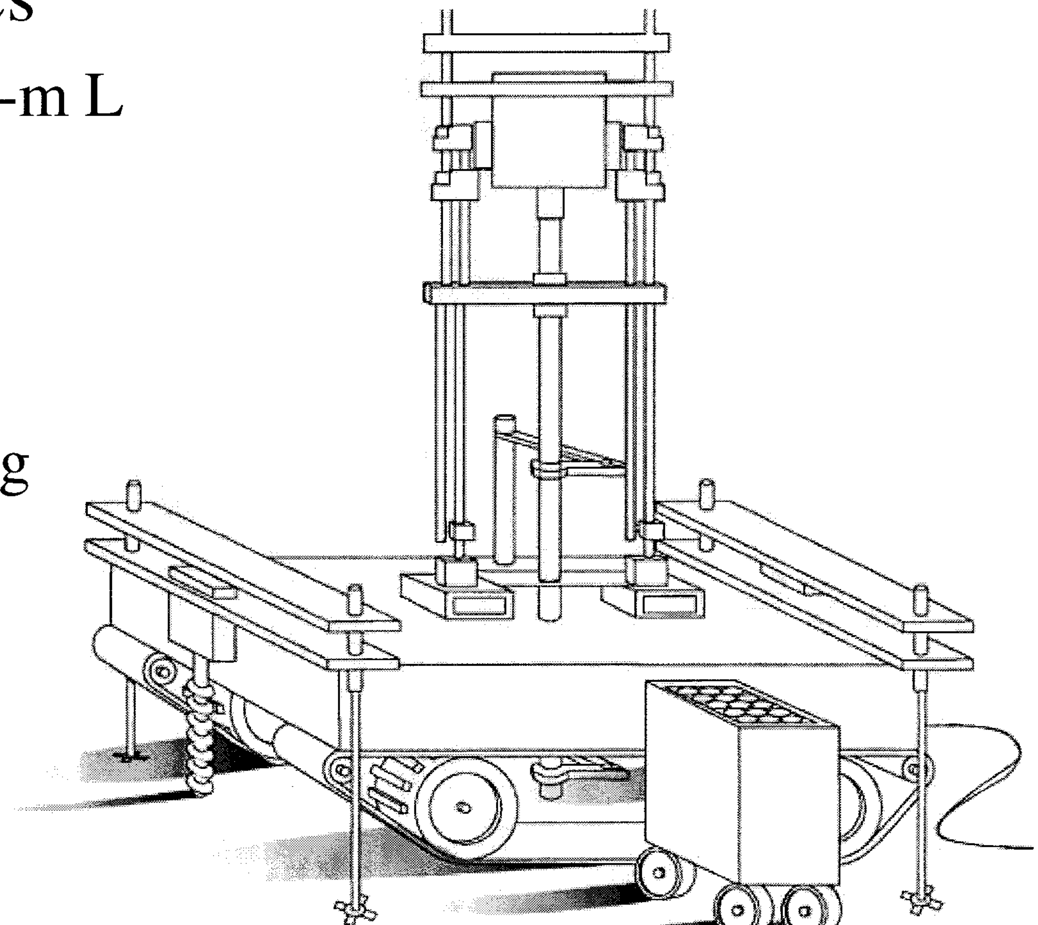
- Nuclear Reactor Concept from NASA Glenn



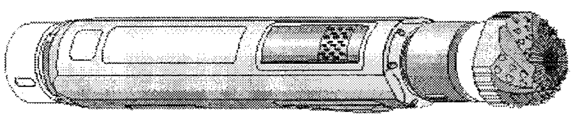
- Characteristics:
  - Deployable Radiators
  - Safety Rods
  - Neutron Reflectors
  - Instrument Shadow Shielding
  - Brayton Power Conversion
  - Power: 20 kWe (variable)
  - Total Mass: 1700+ kg

Mission III: Drilling Campaign (2)

- Deep Drill Characteristics
  - Core Retrieval: 1-cm∅, 1-m L
  - Drill Rate: 1 m per sol
  - Target Depth: 1 km
  - Power Range: 3-5 kW
  - Mass Range:1500-2000 kg



Down-Hole Motor



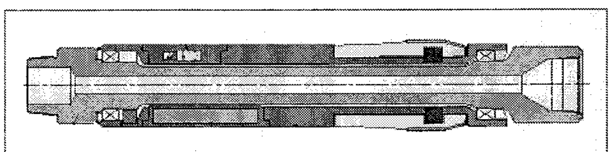
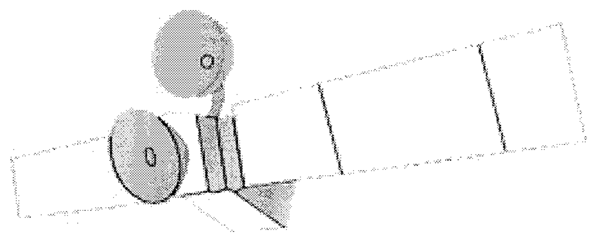


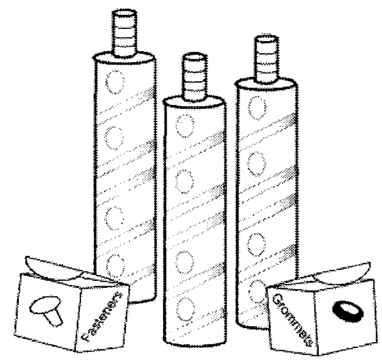
Image Credit: Baker Hughes

Mission III: Drilling Campaign (4)

- Communications Satellite
  - Areostationary Orbit
  - 5-m High Gain Antenna
  - Provides Relay to DNS
  - Possible Libration Point Augmentation

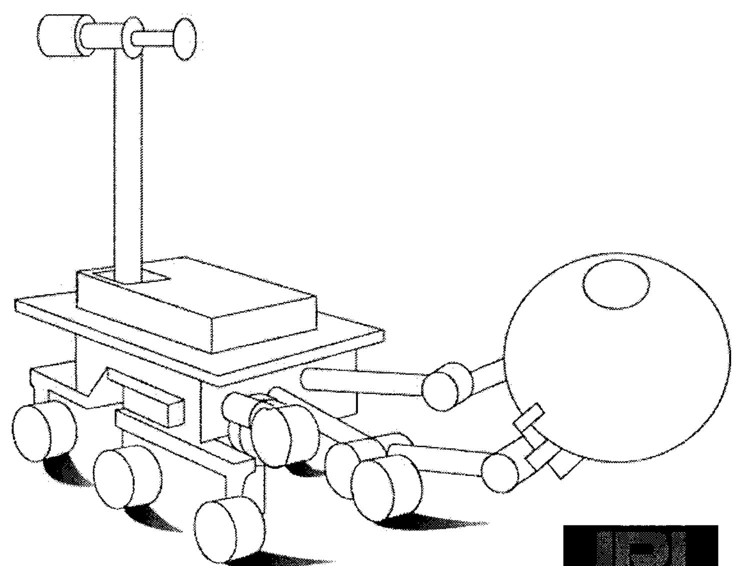


- Logistical Supplies
  - Drill Stems and Casing
  - Replacement Batteries
  - Power Tether



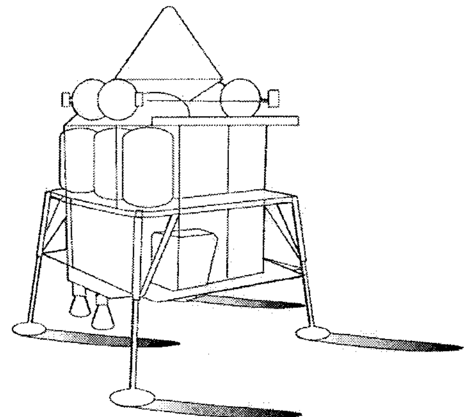
Mission IV: Expanded Science

- Objective: Expand Science Capabilities
- Elements
  - Science Rover
  - Modular Science Packages
  - Logistical Supplies (2 Flights)
- Science Rover
  - Athena Class Rover
  - Carries/Deploys Science Modules
  - Rechargeable Batteries



Mission V: Sample Return

- Objective: Return Scientifically Interesting Samples
- Elements
  - Mars Ascent Vehicle
  - Earth Return Vehicle (orbital)



- Rationale
  - All sample collection assets (rovers, drill, sample analysis equipment) exists already
  - Scientifically selected caches can be launched upon arrival of MAV/ERV or later

Missions VI and VII

- Objectives:
  - Prepare for human exploration
  - Enhance robotic capability and/or prepare for humans
- Elements
  - ISRU Equipment and other Human Precursor Demos
  - Advanced Robotic of Human Gear
  - Advanced Mobile Units
- Rationale
  - At this stage, the outpost should also be rigorously scrutinized and assessed. The decision to expand robotic activities, intensify preparation of the site for human arrival or move to another site determines the future missions.

Water Contingency

- Objectives
  - Shift outpost focus upon discovery of H_2O
  - Understand how to utilize the resource
  - Return "wet" samples
- Elements
  - Wet Chemical Analysis Instruments
  - Wet Sample Return Orbiter and Ascent Vehicle
  - ISRU Systems

Mars Exploration Goals

Life

- Does/did life exist on Mars?
- Search for past/present water

Climate

- What is the past/present climate?
- Study atmosphere and deposits

Geology

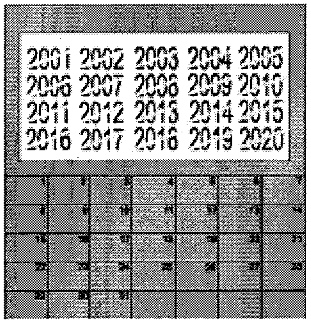
- What is the geological history?
- Characterize the surface/subsurface

Human Preparation

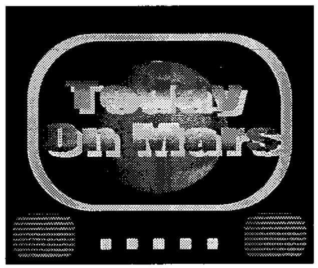
- What is needed for humans?
- Acquire environmental data sets
- Engineering/science demos

Outpost Capabilities

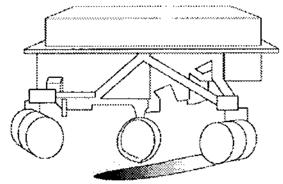
Long-Term Presence



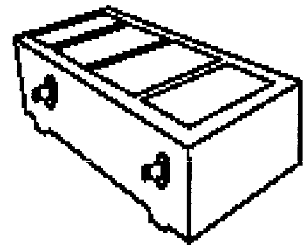
Public Engagement



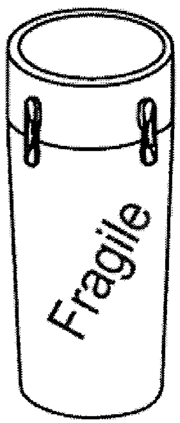
Surface Mobility



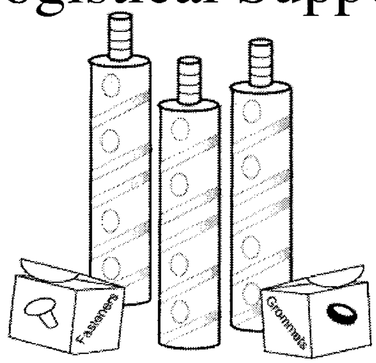
High Power



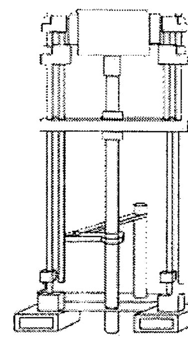
Sample Return



Logistical Support



Subsurface Access

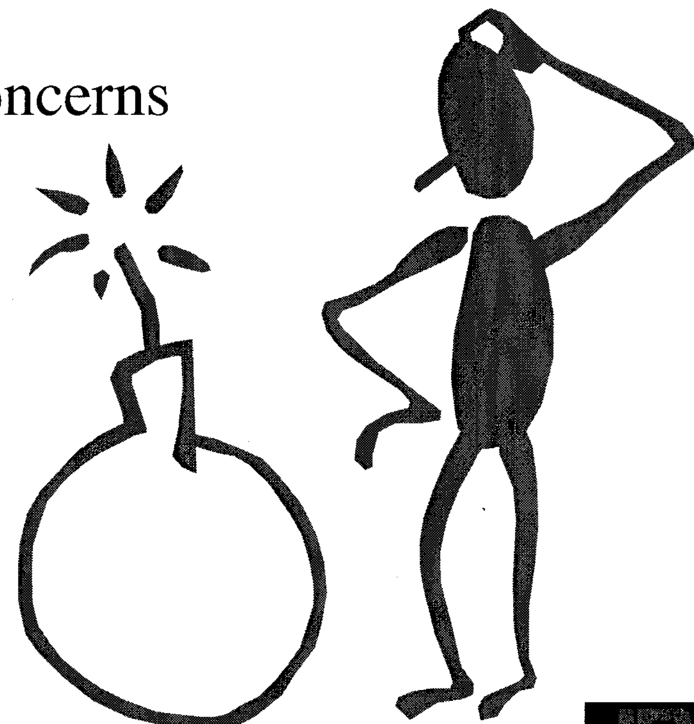


Outpost Capabilities (2)

- MEPAG List
- Enables 30% of investigations
  - Deep Subsurface Access
  - Emplacement of high power systems
- Facilitates another 30%
  - Long-term surface presence
  - Surface mobility
  - Sample return

Findings: Technology Needs

- General Issues
  - EDL Constraints
  - Launch Vehicle Constraints
  - Energy Storage/Transmission Concerns
- Element Specific
  - Reactor
  - Deep Drill
  - Rovers
  - Communications Infrastructure
  - Sample Return Implementation



Findings: Logistics

- Lessons Learned
  - Launch Vehicles Constraints
  - Logistical Mass Drivers
    - Drill Rods
    - Drill Casing
    - Power Tether
  - Life Drivers
  - Reliability Assessment

Acknowledgements

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- Other Contributors
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